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Sonar Estimation of Chinook Salmon in the Yukon River Near Eagle, Alaska, 2005

by

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Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_{2}$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

A new full-scale project was initiated from July 1 to August 13, 2005, to use sonar for a long-term enumeration study of Chinook salmon *Oncorhynchus tshawytscha* on the Yukon River near the Alaska/Canada border. Dual-Frequency Identification Sonar (DIDSON™) and split-beam sonar equipment were tested at Six-Mile Bend, a site 6 miles downriver of Eagle, Alaska. Bottom profiles were produced for precise location of sonar deployment on each bank of the river, an estimate of fish passage was obtained, information on fish distribution was gathered, a drift gillnet test fishery was initiated, and a side-by-side comparison of nearshore detection was undertaken. A total of 81,528 fish were estimated to have passed the sonar site, heading upstream toward the U.S./Canada border between the data collection dates of July 12 and August 10, 2005. In the future, we believe this site will be effective for enumerating Chinook and chum salmon *O. keta* passage into Canada. A long-term enumeration project for Chinook and chum salmon near the border will help fishery managers meet conservation and management commitments made by the U.S. and Canada under the Yukon River Salmon Agreement.

Key words: Alaska, DIDSON™, Eagle, Hydroacoustics, *Oncorhynchus*, salmon, Chinook, chum, split-beam sonar, Yukon River.

INTRODUCTION

A full-scale sonar project was initiated from July 1 to August 13, 2005, to begin a long-term sonar enumeration study of Chinook salmon *Oncorhynchus tshawytscha* on the Yukon River near the Alaska/Canada border. Dual-Frequency Identification Sonar (DIDSON™)[1] and split-beam sonar equipment were tested at Six-Mile Bend, 6 miles downriver of Eagle, Alaska. Sonar equipment was deployed on both banks at the site; an estimate of fish passage was produced; and a drift gillnet test fishery was initiated.

The Yukon River is the largest river in Alaska, spanning 2,300 miles. It flows northwesterly from its origin in northwestern British Columbia through the Yukon Territory and Central Alaska to its mouth at the Bering Sea. Commercial and subsistence fisheries harvest salmon throughout most of the drainage. These salmon fisheries are critical to the way of life and economy of people in dozens of communities along the river, in many instances providing the largest single source of food or income. Management of the fisheries on this river is complex and difficult because of the number, diversity, and geographic range of fish stocks and user groups. Information upon which to base management decisions come from several sources, each of which has unique strengths and weaknesses. Gillnet test fisheries provide inseason indices of run-strength, but interpretation of these data is confounded by gillnet selectivity. Also, the functional relationship between test-fishery catches and abundance is unknown. Mark–recapture projects provide estimates of total abundance, but the information is typically not timely enough to make day-to-day management decisions. Sonar is used to provide timely estimates of abundance, but is limited in its ability to identify fish to species level.

Alaska is obligated to manage Yukon River salmon stocks according to precautionary, abundance-based harvest-sharing principals set by the Yukon River Salmon Agreement (Yukon River Panel 2004). The goal of bi-national, coordinated management of Chinook and chum *O. keta* salmon stocks is to meet escapement requirements that will ensure sufficient fish availability to provide for subsistence and commercial harvests in both the United States and Canada. A daily estimate of fish crossing the border between Alaska and Canada is crucial to meeting the obligations laid out in the Salmon Agreement. Accurate abundance estimates not

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[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

only help managers adjust harvest inseason, they are also used postseason to determine whether treaty obligations were met. Currently the Canadian Department of Fisheries and Oceans (DFO) provides the only estimate of mainstem salmon passage through the Alaska/Canada border using mark–recapture programs, fish wheel test fisheries, and aerial surveys.

Because of the highly turbid water of the Yukon River, and the width of the mainstem (roughly 400 m across at the study site), daily passage estimation methods such as counting towers and weirs are not feasible. Split-beam sonar technology has been used successfully by the Alaska Department of Fish and Game (ADF&G) to produce daily inseason estimates of salmon passage in turbid rivers. Examples include: the lower Yukon River at Pilot Station (Pfisterer 2002) and the Kenai River (Miller and Burwen 2002). DIDSON™ has been used in the Aniak River to give daily passage estimates where bottom profile and river width are appropriate for the wider beam angle and shorter range capabilities of this sonar (McEwen 2005).

In 1992, ADF&G initiated a project near Eagle, Alaska (Figure 1) to examine the feasibility of using split-beam sonar to estimate the number of salmon migrating across the U.S./Canada border (Johnston et al. 1993; Huttunen and Skvorc 1994). This project was the first documented use of split-beam sonar in a riverine environment, and over the 3-year duration of the study a number of problems were identified. Phase corruption was observed and was probably exacerbated by the highly reflective river bottom (Konte et al. 1996). The errors in the phase measurement were believed to have resulted in overly restrictive echo angle thresholds. Echoes from fish that were physically within accepted detection regions were removed from the data files because of errors in angle measurement. These and other equipment issues reflected the early state of development of the new equipment, most of which have since been addressed.

Some recommendations from the early border sonar studies were to find a better site with smaller rocks and a smoother bottom profile (Johnston et al. 1993). Too many large rocks or obstructions in the profile can compromise fish detection by limiting how close to the bottom the hydroacoustic beam can be aimed. Similarly, an uneven bottom may have allowed fish to pass undetected by the sonar, and a more linear profile would alleviate this problem and allow detection of fish at longer ranges.

In 2003, ADF&G carried out a study to identify a more suitable location to deploy hydroacoustic equipment to estimate salmon passage into Canada. A 28-mile section of river from the DFO mark–recapture fish wheel project at White Rock, Canada, to 12 miles below Eagle, Alaska, was explored (Pfisterer and Huttunen 2004). This area was investigated because of its proximity to the DFO project, and the U.S./Canada border. Criteria for suitable sites were: linear bottom profiles on both sides of the river without large obstructions; a single channel; available beach above water level for topside equipment, and sufficient current, i.e., areas without eddies or slack-water where fish milling behavior can occur. A total of 21 river bottom-profiling transects led to narrowing of potential project locations to an area between 6 and 15 miles downriver from the town of Eagle. The 2003 study found that the two most promising sonar deployment locations meeting the above criteria were Calico Bluff and Shade Creek. Though sonar was not deployed in 2003, the bottom profiles at the preferred sites indicated that it should be possible to enumerate fish passage with a combination of split-beam on the longer, linear bank, and DIDSON™ on the shorter, steeper bank.

After finding a suitable section of river for a potential sonar project in 2003, ADF&G carried out a 2-week study within the above suggested study area in 2004 to test sonar at the preferred sites.

Two types of sonar were tested at Calico Bluff and the Shade creek area. It was found that Six-Mile Bend (0.5 mile upriver of Shade creek) was the most ideal site, and that a DIDSON™ should be deployed on the shorter, steeper bank, and a split-beam unit should be deployed on the longer, more linear left bank (Carroll et al. 2007). The current study is a full-scale enumeration project during the Chinook salmon run, and incorporation of a test fishing program for species composition, at the Six-Mile Bend site proposed in 2004.

Gaining a better understanding of species composition, behavior, and spatial distribution of the fish passing the Eagle sonar project will be important for future operations. No attempt at species apportionment was made in the current study.

STUDY AREA

The study area was a 1-mile section of the mainstem Yukon River at Six-Mile Bend, 6 miles below Eagle, Alaska (Figure 2).

Average monthly discharge for the Yukon River ranges from 110,500 to 223,600 ft^3/s. Flows are highest in June, with greatest variability in flow occurring in May, after which flow slowly declines and varies only slightly. The Upper Yukon River is turbid and silty in the summer and fall with an estimated annual suspended-sediment load at Eagle of 33,000,000 tons (Brabets et al. 2000).

The Hungwitchin Native Corporation owns the majority of land in the study area above the ordinary mean high water mark. Permission was granted to operate a sonar project on Hungwitchin Corporation land at Six-Mile Bend. A semi-permanent field camp was constructed on the left bank (facing downstream) at Six-Mile Bend (64° 51’55.70” N 141° 04’43.62” W) consisting of 6 canvas wall tents with plywood platforms and an outhouse. A removable canvas sonar tent was constructed on the left bank 0.5 miles downriver from camp (64°52’30.84” N 141°04’52.77” W) and a portable wooden shelter was used on the remote right bank to house sonar topside equipment.

OBJECTIVES

The primary goals of this project are to use sonar technology to estimate the timing and magnitude of adult Chinook salmon migrating past the sonar site at Six-Mile Bend, and to characterize age and sex composition of the Chinook run. Specific objectives are outlined as follows:

- Use sonar to estimate daily and seasonal passage of Chinook salmon at Six-Mile Bend from approximately July 10 to August 10, 2005;
- Initiate a drift gillnet test fishery for investigation of species composition at the site;
- Collect daily climate and hydrological measurements representative of the sonar project area;
- Estimate the age, sex, and length (ASL) composition of the Yukon River Chinook salmon return based upon sampled portions of the run; and
- Collect Chinook salmon fecundity samples as well as tissue samples for genetic stock identification projects.

METHODS

Hydroacoustic Equipment

A fixed-location, split-beam fisheries hydroacoustic system developed by Kongsberg Simrad was used to estimate salmon abundance on the left bank. Fish passage was monitored with a model EK60 digital echo sounder which included a general purpose transceiver and a 4° by 10° 120 kHz transducer. A laptop computer connected to the echosounder provides access to the ER60 data acquisition software that collects the raw data that can be saved for future use. Digital files were created by the ER60 software and edited in *Echoview*® software to produce an estimate of fish passage.

The transducer was attached to 2 Hydroacoustic Technology Incorporated (HTI) model 662H single-axis rotators. Aiming was achieved remotely using a HTI model 660 remote control unit that provided horizontal and vertical position readings.

The transducer and rotators were mounted on a pod made of aluminum pipe and deployed approximately 15 m offshore. The pod was secured with sandbags and the transducer height was adjusted by sliding the mount up or down along riser pipes that extended above the water. The transducer was deployed in water ranging from approximately 1.0 m to 1.5 m in depth and was aimed perpendicular to the current along the natural substrate. The deployment location was in the main channel with no eddy or slack water.

An artificial acoustic target was used at various distances from the transducer during deployment to verify that the transducer aim was low enough to prevent salmon from passing undetected beneath the acoustic beam and to test target detection over different ranges. The target, an airtight 250-ml weighted plastic bottle tied with fishing line, was drifted downstream along the river bottom and through the acoustic beams. Several drifts were made with the target in an attempt to pass it through as much of the counting range as possible. Because the target was only used to test the aim and the range of detection, x-y plots of the target strength of the target were not used to test if it was comparable to that of a fish. Proper aim for the split-beam system was verified with visual interpretation of an echogram on a computer screen, i.e. with visible but not overpowering return of bottom signal appearing over the majority of the ensonified range.

One DIDSON™ long-range unit manufactured by Sound Metrics Corp. was deployed on the right bank. This sonar was operated at 0.70 MHz, its low frequency option, using 48 beams with a viewing angle of 29° by 12°. The maximum window length was set at 40 m. The DIDSON™ was mounted on an aluminum pod and aimed using an automated rotator similar to the one described above. Operators adjusted the aim while viewing the video image. Proper aim was achieved when adequate bottom features appeared over the majority of the ensonified range (0–40 m).

The sampling was controlled by DIDSON™ software loaded on a laptop computer. A 50-m cable carried power and data between a “breakout box” and the DIDSON™ unit in the water. All surface electronics were housed on the beach in a small wood frame shelter. Portable 1000-watt generators were used to power the equipment on both sides of the river. A wireless router transferred data between the breakout box and the laptop in the tent on the opposite shore.

Sonar Deployment and Operation

Transects were made across the Yukon River at Six-Mile Bend, to create bottom profiles of the site for precise location of sonar equipment deployment. Profiles of the river bottom were collected and saved during transects, using a boat mounted Lowrance LCX-15 dual-frequency transducer (down-looking sonar) with a built-in Global Positioning System (GPS). Bottom profiles were then generated using data files uploaded to a computer and plotted with Microsoft® *Excel* in the field. A total of 57 transects were made from bank to bank at roughly 30-m intervals, not including aborted attempts. Areas where topside equipment could not be deployed were not profiled, e.g. bluffs, where rock walls rose out of the water. Sonar deployment sites were selected based on a profile consisting of a steady downward sloping gradient without large dips or obstructions that hinder full acoustic beam coverage or detection of targets, with sufficient current containing no eddies, and sufficient beach above water line to house topside sonar equipment.

The DIDSON™ unit was deployed from July 10 to August 10 on the right bank at Six-Mile Bend. A fish lead was constructed with 2 m metal "T" stakes and 1.2 m high galvanized chain-link fencing. The fish lead was set-up approximately 1.5 m downstream shoreward of the right bank DIDSON™ transducer and extended out to 2 m in front of the transducer to provide adequate fish diversion through the ensonified zone. A short lead was appropriate for this bank because of the steep drop off (water depth approximately 2 m, 3 m from shore) and the short nearfield distance (0.83 m) of the DIDSON™. The river was ensonified to a range of 40 m from the transducer, with 2 sampling zones, ranging from approximately 1 to 20 m and 20 to 40 m. Sonar control parameters included: 0.83 m window start, 20.01 m window length, high frequency mode, and 7 frames per second for the first zone, and 20.84 m window start, 20.01 m window length, low frequency mode, and 4 frames per second for the second zone.

From July 10 to August 10, the split-beam sonar was deployed on the left bank at Six-Mile Bend. A 1.2 m high galvanized chain-link fish lead with 2-m metal "T" stakes was set up shoreward 1.5 m downstream of the left bank split-beam transducer to prevent fish passage inshore of the transducer. The fish lead extended 7 m offshore of the transducer, providing adequate fish diversion through the ensonified zone. The split-beam system was aimed to ensonify to a range of approximately 150 m (total river width at the site was approximately 400 m). Settings for data acquisition included: 5 pings per second, 256µs transmit pulse lengths, 500-watt power output, and 2 to 150 m range.

SONAR DATA PROCESSING AND ABUNDANCE ESTIMATION

Split-beam data were collected by the data acquisition software in 60-minute samples each hour of the day (no temporal sampling) and saved as .RAW files to an external hard drive for tracking and counting. The operator opened each .RAW data file in *Echoview*® and used 2 echograms to view and count fish. The target strength (TS) raw pings echogram was viewed alongside the horizontal angle echogram (masked by TS data range bitmap) echogram. The 2 echograms were scrolled through simultaneously and tracks that appeared on the TS echogram were located on the horizontal angle echogram to see if their coloration indicated an upstream direction of travel (i.e. red to blue). All upstream fish tracks were counted with a tally counter and the number of upstream fish for each file was recorded on a count form. Three split-beam files per day were tracked (0300, 1100, and 1900 hours). Tracking involved selecting the group of echoes that made up a fish track. These fish tracks were saved as text files and used to examine range and target strength distributions.

DIDSON™ data were collected in two 30-minute range samples per hour. For the first 30 minutes of every hour, the DIDSON™ sampled the ensonified range from 1 to 20 m (zone 1) and the second half of each hour sampled from 20 to 40 m (zone 2). Upstream migrating fish were counted by marking each fish trace on the DIDSON™ echogram. Direction of passage for each fish was verified using the DIDSON™ video. The count for each 30-minute sample was multiplied by 2, and the 1–20 m and 20–40 m counts were summed for a total hour count for that bank. Since sonar counts are highly auto correlated, treating the systematically sampled sonar counts as a simple random sample would yield an over-estimate of the variance of the total. To accommodate these data characteristics, a variance estimator based on the squared differences of successive observations was employed. The daily passage for zone *z* on day *d* was calculated by summing the hourly passage rates for each hour as follows:

$$\hat{y}_{dz} = \sum_{p=1}^{24} \frac{y_{dzp}}{h_{dzp}} \tag{1}$$

Where h_{dzp} is the fraction of the hour sampled on day *d*, zone *z*, period *p* and y_{dzp} is the count for sample *p* in zone *z* of day *d*.

The variance for the passage estimate for zone *z* on day *d* is estimated as:

$$\hat{V}_{y_{dz}} = 24^2 \frac{1-f_{dz}}{n_{dz}} \frac{\sum_{p=2}^{n_{dz}} \left(\frac{y_{dzp}}{h_{dzp}} - \frac{y_{dz,p-1}}{h_{dz,p-1}} \right)^2}{2(n_{dz}-1)} \tag{2}$$

Where n_{dz} is the number of samples in the day (24) and f_{dz} is the fraction of the day sampled (12/24=0.5). y_{dzp} is the hourly count for day *d* in zone *z* for sample *p*.

Since the passage estimates are assumed independent between zones and among days, the total variance was estimated as the sum of the variances:

$$\hat{V}ar(\hat{y}) = \sum_{d}\sum_{z} \hat{V}ar(\hat{y}_{dz}) \tag{3}$$

The reported variance reflects the sampling done on the right bank. There was no sampling variance for the left bank since the left bank sampled the entire range continuously. The counts from each split-beam and DIDSON™ sample were entered into a Microsoft® *Excel* spreadsheet where counts were adjusted for periods when data was not collected. When a portion of a sample was missing, passage was estimated by expansion based on the known portion of the sample. The number of minutes in a complete sample was divided by the known number of minutes counted and then multiplied by the number of fish counted in that period. If data from 1 or more complete samples was missing, counts were interpolated by averaging counts from samples before and after the missing sample or samples.

TEMPORAL AND SPATIAL DISTRIBUTIONS

Fish range distributions were examined postseason by importing the text files containing all fish track information into the *R statistical software package* (R Development Core Team 2004). Data from the tracked split-beam files provided vertical distribution information which could be used for plotting fish distribution in the water column. On July 23rd the DIDSON™ was turned 90 degrees on its side (so that the 48 beams were spread vertically in the water column as opposed to the normal horizontal aspect) and was operated for 24 hours to collect vertical distribution data for the right bank. Histograms were made of the fish distributions and were used to investigate the spatial behavior of fish passing the sonar site. Histograms of passage by hour were created in Microsoft® *Excel* to investigate diel patterns of migration.

TEST FISHING AND SAMPLING

Drift gillnets were used at the sonar site as the method of test fishing to sample for species composition, and for collecting age, sex, and length (ASL), genetic and fecundity information from Chinook salmon. Six gillnets each with different mesh size were fished in an effort to effectively capture all size classes of fish present and detectable by the hydroacoustic equipment. All nets were 25 fathoms (45.7 m) long and 5 fathoms (7.6 m) deep. Nets were constructed of Momoi Monotwist, shade 11, double knot multifilament nylon twine, and hung with an even 2:1 ratio of web to cork. Mesh sizes were 2.75 in (70 mm), 4.0 in (102 mm), 5.25 in (133 mm), 6.5 in (165 mm), 7.5 in (191mm), and 8.5 in (216 mm). Drifts occurred in an area of the river 400 m upstream to 400 m downstream of the sonar site. Three zones within the sonar sampling range were drifted: the right bank nearshore (RN), the left bank nearshore (LN), and the left bank offshore (LO). The drift in the RN zone lasted about 6 minutes and covered the area ensonified by the DIDSON™ (approximately 40 m). The drift in the LN zone took approximately 6 minutes and LO zone took 8 minutes, and these 2 drifts covered the area ensonified by the split-beam on left bank (approximately 150 m). The drift times of the2 nearshore drifts were intended to be 8 minutes, but underwater snags required a shortening of the drift time. Three nets (of different mesh sizes) were drifted once in each zone during Period 1 which occurred from 0900 hours to 1200 hours, and then the same 3 nets were fished the next day during Period 2 from 1400 hours to 1700 hours. On the third day, the other 3 mesh sizes were fished during Period 1, and then on day four the same 3 were fished during Period 2. Thus, each net was fished for each of the 3 sampling zones for 2 consecutive days over 2 time periods (Table 1). The drift test fishing was begun on July 11 and continued every day through August 10, 2005.

Four times were recorded to the nearest second onto field data sheets for each drift: net start out (*SO*), net full out (*FO*), net start in (*SI*), and net full in (*FI*). For each drift fishing time (*t*), in minutes, was approximated as:

$$t = SI - FO + \frac{FO - SO}{2} + \frac{FI - SI}{2} \tag{4}$$

Total effort *e*, in fathom-hours, of drift *j* with mesh size *m* during test-fishing period *f* in zone *z* on day *d* was calculated as:

$$e_{dzfmj} = \frac{25\,t_{dzfmj}}{60} \tag{5}$$

ASL, genetic and fecundity sampling was conducted on all captured Chinook salmon. For standard ASL samples, length (mideye to tail fork to nearest 5 mm), and sex (determined by internal inspection of gonads) were recorded. Three scales were removed from the preferred area on the left side of the fish, approximately 2 rows above the lateral line, in an area transected by a diagonal line from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Clutter and Whitesel 1956). All scale samples were cleaned and mounted on gum cards to be aged by the ADF&G ASL lab in Anchorage, Alaska. These scale data are used to estimate the age composition of the Chinook that pass the sonar site. Additionally, axillary processes were clipped from Chinook, stored in vials of ethanol, and sent to the ADF&G genetics lab for processing in Anchorage, Alaska. Girth and weight of Chinook were also recorded for a separate fecundity study. Non-salmon species were measured from nose to tail fork, but were not sampled for other data. Captured fish were distributed to local residents after sampling.

A 6.5-inch mesh gillnet was set from shore on August 4 for 48 hours to explore the possibility of using set nets at the site in future. The net was set 100 meters upriver from the split-beam sonar on left bank. The net was staked on shore and then anchored out into the current with a heavy weight attached to the lead line. The net was not located in an eddy, as the intent was to capture what was passing close to shore near the sonar site.

CLIMATE AND HYDROLOGICAL SAMPLING

Climate and hydrologic data were collected daily at approximately 2000 hours at the sonar site. Water temperature was measured in degrees Celsius near shore at a depth of approximately 30 centimeters. Air temperatures were recorded in degrees Celsius. Subjective notes on wind speed and direction, cloud cover, and precipitation were also recorded. Although reported water levels are taken from the U.S. Geological Survey's water gauge at Eagle, a stream gauge was used to track water level at the sonar site inseason.

ADDITIONAL INVESTIGATIONS

On July 24 the DIDSON™ was moved to the left bank and deployed about 1.5 m downriver of the split-beam transducer. The 2 systems were operated side-by-side for 26.5 hours. The purpose of this side-by-side operation was to look at fish behavior at the end of the fish lead (i.e., fish moving around the fish lead and then in towards shore), to check for the presence and relative abundance of small non-salmon species, and to check for bias in the split-beam counts within the first 20 meters of the ensonified zone. The 2 sonar devices collected twenty-five 60-minute samples and one 30-minute sample during the period of side-by-side operation on the left bank.

Nearshore detection

Because the maximum ping rate is limited by the maximum counting range, there existed the possibility that fish passing close to the transducer (less than 20 m) would not be detected by the split-beam sonar due to the relatively slow ping rate and narrow beam nearshore. To examine whether this was a problem, the split-beam and DIDSON™ were operated side-by-side and aimed such that they were ensonifying the same region of fish passage. Fish passage estimates out to 20 m were produced for each system using the same protocol as would be used during normal operation. Standard regression methods were used to examine for bias in the split-beam counts.

Small, non-salmon species

Target strength distributions from the split-beam data were used to assess the presence of multiple size classes of fish which would indicate an abundance of non-target species. We also examined the DIDSON™ files during this paired data collection for the presence of small, non-salmonid species moving upstream which could have been incorrectly identified as Chinook salmon. Downstream fish were ignored because they were not counted under normal processing conditions. Small non-salmon fish were detected primarily by shape of trace on the echogram. They often produce a faint, long, wiggly trace, and do not resemble the dense, bright trace of migrating fish moving through at constant, relatively fast speed. If small fish were seen on the echogram or video, their range, direction of travel, and time of passage was noted. Targets were then measured with the measuring tool on the DIDSON™ program. To compare these small targets with the larger targets assumed to be upstream migrating Chinook, tracks at equivalent ranges (within 0.5 meter) were picked randomly from the echograms and measured. When small fish targets were found in the DIDSON™ files, they were located at the same time and range on the split-beam files. This allowed us to determine whether the split-beam system was detecting the smaller fish, and what the traces looked like on the split-beam echograms.

Fish behavior

This was a qualitative examination of whether there were large numbers of fish passing the end of the weir and then swimming immediately towards shore. This sort of behavior, if present, could reduce fish detection by the split-beam sonar. Behavior was examined postseason, by looking at each fish target on the echogram and video display of the DIDSON™ files collected during the side-by-side operation period, and noting any unusual fish behavior such as fish swimming inshore directly towards the transducer from the end of the fish lead. Other deviant swimming patterns were also noted, such as lingering in the beam, and then leaving the beam on the downstream side.

Thalweg investigation

The DIDSON™ was used in 2 ways to investigate whether or not sonar could be used to test for presence or absence of fish in the thalweg and unensonified region of the river. On July 31, the DIDSON™ was attached to a telescoping mount on the boat. The boat was anchored above the thalweg, using a range finder and a known distance from shore. A second method was attempted on August 1. The DIDSON™ was attached to the same boat-mount, but this time the boat was allowed to drift parallel to shore along the thalweg, instead of anchoring in a single location.

RESULTS

SONAR DEPLOYMENT

The left bank sonar was deployed approximately 800 m down river from the camp, and the right bank sonar was deployed across river and approximately 700 m downriver from camp (Figure 2). Figure 3 shows zones of ensonification and bottom profile of the Yukon River at Six-Mile Bend sonar site. The left bank profile is approximately linear, extending 300 m to the thalweg at a 3.7% slope. The right bank profile is less linear, but shorter and steeper (9.7% slope), extending 100 m to the thalweg. The substrate at Six-Mile Bend is large cobble to small boulder on the right bank, and small-to-medium size cobble and silt on the left bank.

ABUNDANCE ESTIMATION

The total Chinook passage estimate at the Eagle sonar site was 81,528 for the dates of July 12 through August 10, 2005. Table 2 shows the daily and cumulative counts for the season, as well as the passage quartiles. Daily passage estimates were relayed to the fishery managers in Fairbanks every morning via satellite telephone.

TEMPORAL AND SPATIAL DISTRIBUTION

Fish were shore oriented on both banks (Figure 4). On the left bank, 90% of the fish were detected within 40 m of the transducer and 95% within 50 m. On the right bank, 90% of the fish were detected within 20 m of the transducer and 95% within 25 m. Figure 5 shows the vertical distribution of targets for left and right banks. Over 95% of all targets marked on the left bank were found along the lower half of the hydroacoustic beam and on the right bank almost 100% were in the lower half of the beam. Overall there does not appear to be much of a diel fluctuation at the project site, although each side of the river independently showed a slight diel fluctuation

(Figure 6). The percentage of fish passage estimated by bank for the season was 39% on the right bank and 61% on the left bank.

TEST FISHING AND SAMPLING

In 2005, 179 Chinook salmon (121 males; 58 females) were captured in 277 drifts between July 10 and August 10 (Table 3). The drift gillnets were fished a total of 853 fathom hours. A majority of the Chinook (77%) were captured on the left bank nearshore drifts, while 17% were captured on the offshore drift, and only 6% were captured on the right bank drifts. From the 179 scale samples collected 171 were readable. From these readable samples it was determined that age-1.3 fish predominated (50.3%) followed by age-1.4 (36.8%), age-1.2, and age-1.5 were 8.2% and 2.3% respectively, and age 2.3 and 2.4 were both 1.2% (Bales 2007). A single whitefish *Coregonus* sp (not keyed to species) was also captured. Two chum salmon were caught in a gillnet set from shore that fished for 48 hours beginning August 4. Table 4 lists the average length of Chinook captured, and effort by mesh size.

CLIMATE AND HYDROLOGICAL OBSERVATIONS

The water level remained relatively high at the project site through 2005, with the highest level recorded on July 11. With respect to the initial water level on July 11, the water level fell 2.5 ft during the first 7 days then gained 1.4 ft between July 18 and July 23. From July 23 to July 29, the water level dropped 2 ft before rising again 1.5 ft over the next 5 days. The water level dropped continuously during the remainder of the project except for the last day when it gained 0.3 ft. Final measurement on August 11 was 2.5 ft below the initial level. Water temperature at the project site ranged from 12º to 18°C based upon instantaneous surface measurements, and averaged 15°C. Appendix A1 shows details of weather and water temperature observations recorded at the sonar site. Figure 7 shows U.S. Geological Survey (USGS) water levels measured at Eagle during project operation, as well as water level averages for 1984 to 2004.

ADDITIONAL INVESTIGATIONS

Nearshore detection

Regression analysis shows there was a significant positive relationship (R^2 = 0.842, p<0.001) between the counts obtained with the split-beam and the DIDSON™ (Figure 8; Figure 9). The slope of the line (1.065) was close to one and the 95% confidence interval of the regression includes the one-to-one line.

Small, non-salmon species

A total of 230 fish were observed on the DIDSON™ files used for comparison/analysis. Of those, 18 (7.8%) were small fish exhibiting behavior not associated with salmon migrating upstream. These small fish were all found within 10 meters of the transducer, and 11 of them (62%) were between the offshore end of the fish lead and the transducer. Only 50% of the small fish were detected by the split-beam system. The average size of the small fish targets was 41 cm, and the average size of the fish targets exhibiting migrating salmon behavior, measured at equivalent ranges, was 82 cm. The split-beam target strength distribution had a single mode with an average for all tracked fish of -27 dB. For the 24 hrs of DIDSON™ data that was analyzed from the right bank, only 6 small upstream fish were found, all within 10 meters of the transducer. This represents about 0.07% of the right bank passage.

Fish behavior

From the 24 hours of left bank DIDSON™ data analyzed for fish behavior, only 1 salmon-sized fish out of 277 was seen to exhibit behavior associated with fish lead avoidance, i.e. where the fish swam from the end of the fish lead straight in towards the transducer. Its trajectory was still considered to be upstream, as it left the upstream side of the beam.

Thalweg investigation

Because of a problem with the computer's network card, no data was collected during the first deployment. The next day, data was collected from 5 drifts. The velocity of the current and boat made the data from these drifts unusable.

DISCUSSION

SONAR DEPLOYMENT, OPERATION, AND CHINOOK ESTIMATE

The split-beam and DIDSON™ systems performed optimally over the entire season with no technical difficulties or issues. The DIDSON™ was the ideal system for the right bank, where the profile is steep and slightly less linear than the left bank. The split-beam system worked without malfunction, and appeared to have a satisfactory detection rate nearshore, while still detecting targets adequately at 150 m.

Processing procedures for marking both DIDSON™ and split-beam files appeared to work well for estimating salmon passage at the site. All data files were easily processed in a reasonable amount of time. Improvements of processing procedure are an ongoing endeavor.

The main purpose of this study was to estimate the passage of Chinook salmon to Canada in the mainstem of the Yukon River using hydroacoustics, and to characterize age and sex composition of the run. The results of this first season suggest that is will be possible to provide daily escapement estimates to area fishery managers in the future. The estimate of 81,528 Chinook is almost double the preliminary Canadian fish wheel mark recapture estimate of 42,245 (JTC 2006). In future seasons it may be necessary to account for (subtract) the subsistence catch, from upstream of the project site to the border, in the estimate. Continuing both the DFO and ADF&G projects for a number of years will allow managers to determine if there is any relationship between the 2 estimation methods, and whether the border passage goals should be revised.

TEMPORAL AND SPATIAL DISTRIBUTIONS

The vertical distributions show that the majority of the fish detected with the sonar are swimming close to the bottom and not over the ensonified region. The range distributions also show that on both banks, the majority of fish were within 40 m of shore. Based on the vertical and range distributions observed this season, we do not believe there were many fish migrating upstream in the unensonified portion of the river. Because the majority of the fish were seen at less than the maximum ensonified range, a sampling plan for future seasons with a similar range for left and right banks should be adequate for Chinook enumeration. Because chum salmon tend to swim closer to shore, it may be appropriate to sample a shorter distance on left bank during chum season, or to try a multiple-strata sampling scheme to maximize detection in the nearshore and offshore separately (subject to equipment limitations).

TEST FISHING AND SAMPLING

The number of fish caught in the drift gillnet test fishery this season was not a sufficient sample size to make conclusions about species composition in the river and, if this method of test fishing is used for species apportionment at the site, the methodology will need to be modified. The fact that no chum salmon were caught in the drift gillnets may indicate that there were very few chum salmon passing or that the fishing methods were not satisfactory. Chum salmon and non-salmon species such as whitefish are locally known to migrate near shore, so other methods of sampling should be investigated. Because 2 chum salmon were caught in the gillnet which was set from shore during the 48-hour period, there is an indication that a shore-based sampling method might capture chum and other species better than the drifting method. For a set net, much shallower suite of gillnets would need to be used and, because of the current near the sonar site, a double-weighted lead line might be necessary. The set net that was used this season was probably resting on the river bottom, but much of the mesh was splayed across the water surface due to the swift current, which may be an indication that even a shallower net may not fish optimally because of the current. A method that was not attempted, but may be worthy of investigation, is the 'beachwalk' (Fleischman et al. 1995). This method consists of walking down the beach with a gillnet that is attached to a drifting boat.

The maximum daily fish passage rate was on July 23, and was 2.4 fish/min on left bank, and 1.7 fish/min on right bank. The minimum daily passage rate during the season was on August 9 and was 0.31 fish/min on left bank, and 0.10 fish/min on right bank. Because these rates represent the entire range ensonified for each bank, the likelihood of a fish encountering a net at this low rate of occurrence is relatively small, and may be a major contributing factor as to why not many fish were caught in the driftnets over the course of the season. Given our location and sampling methods it would be difficult or too time consuming to capture many more Chinook during the season. Although only 179 Chinook salmon were captured, all were sampled for age, sex, length, girth, and genetics. The ASL, genetic, and fecundity samples collected will add to our knowledge of the fishery.

ADDITIONAL INVESTIGATIONS

Nearshore detection

The results of the side-by-side comparison showed a significant positive correlation from 0 m to 20 m. The regression, with the slope close to one and the 95% confidence interval including the one-to-one line suggests that although the ping rate may not be ideal for this range, it is not adversely affecting counts in the nearshore region.

Small, non-salmon species

The percentage of small fish observed at the site not exhibiting migrating salmon behavior does not appear to be large enough to be a concern at this time. The relative proportion of species other than Chinook is less than 10% of the total estimated passage. Since the smaller fish were detected infrequently on the split-beam system, we do not believe we were counting many of the small non-salmon species. These small fish also have distinctive traces on the DIDSON™, which allowed us to exclude them from the counts.

Fish behavior

Unusual fish behavior seems to be an insignificant occurrence at the site. Only 1 salmon-sized fish was observed swimming around the fish lead and straight toward the transducer during the 24-hr behavioral analysis period with no other unusual behavior observed. This gives additional confidence that the split-beam system was adequately detecting fish migrating close to the end of the weir.

Thalweg investigation

No quantitative results were achieved with the boat-mounted DIDSON™ methods attempted. The current at the sonar site in the thalweg was incredibly swift. It quickly became apparent that there were 2 problems with this anchoring method. The first problem was that because the current was so swift, and the thalweg was 10.5 m deep, the amount of weight and line needed to anchor the boat was considerably large. Getting the boat to anchor in the current proved to be dangerous, and removing the anchor once the exercise was completed was deemed to be too difficult for safe and normal operation. A second problem with anchoring the boat was that the turbulence and disturbance around the DIDSON™ unit created by the boat being stopped in the water would have rendered any images unusable. Even with a much longer boat mount which might have gotten the DIDSON™ deeper into the water to avoid the turbulence, it was decided that the anchoring process was not safe enough to attempt again. The second method of drifting in the boat avoided the turbulence around the DIDSON™ and images of the bottom were obtained, but because the current is so swift, the boat and DIDSON™ were moving through the water so quickly that it would be impossible to detect a fish moving through the beams, so the method was abandoned. Though it is probable that fish are migrating in the unensonified portion of the river, the fish range distributions show the majority of fish are passing close to shore. If fish are being missed outside of the ensonified range, the percentage of the total passage is likely sufficiently small to be considered insignificant. Given the difficulty of this deployment we are not planning on continuing the thalweg investigation in the future.

ACKNOWLEDGMENTS

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TABLES AND FIGURES

Table 1.–Eagle sonar project fishing schedule, 2005.

Period	Day 1	Day 2	Day 3	Day 4
1 (0900–1200)	4.0"		2.75"	
	6.5"		5.5"	
	8.5"		7.5"	
2 (1400–1700)		4.0"		2.75"
		6.5"		5.5"
		8.5"		7.5"

Table 2.–Estimated daily and cumulative Chinook salmon passage by bank, Eagle Sonar, 2005.

	Daily			Cumulative			
Date	Right Bank	Left Bank	Total	Right Bank	Left Bank	% of Total Passage	Total
7/12	433	1,098	1,531	433	1,098	0.02	1,531
7/13	1,396	1,222	2,618	1,829	2,320	0.05	4,149
7/14	1,388	1,734	3,122	3,217	4,054	0.09	7,271
7/15	1,580	1,662	3,242	4,797	5,716	0.13	10,512
7/16	1,870	1,900	3,770	6,667	7,616	0.18	14,283
7/17	2,272	1,801	4,073	8,939	9,417	0.23	18,355
7/18	2,720	1,760	4,480	11,659	11,177	0.28	22,835 [a]
7/19	2,184	2,529	4,713	13,843	13,706	0.34	27,548
7/20	1,924	2,744	4,668	15,767	16,450	0.40	32,216
7/21	1,988	3,266	5,254	17,755	19,716	0.46	37,470
7/22	1,323	3,821	5,144	19,077	23,536	0.52	42,614 [b]
7/23	2,482	3,474	5,956	21,559	27,010	0.60	48,570
7/24	960	2,803	3,763	22,519	29,813	0.64	52,333
7/25	888	2,431	3,319	23,407	32,244	0.68	55,652
7/26	780	1,693	2,473	24,187	33,937	0.71	58,124
7/27	846	1,614	2,460	25,034	35,551	0.74	60,584
7/28	904	1,800	2,704	25,938	37,351	0.78	63,288
7/29	1,076	1,754	2,830	27,013	39,105	0.81	66,118
7/30	700	1,847	2,547	27,713	40,952	0.84	68,665
7/31	670	1,852	2,522	28,383	42,803	0.87	71,186
8/01	372	1,304	1,676	28,755	44,107	0.89	72,862
8/02	314	1,049	1,363	29,069	45,156	0.91	74,225
8/03	432	1,005	1,437	29,502	46,161	0.93	75,663
8/04	456	790	1,246	29,958	46,951	0.94	76,909
8/05	484	574	1,058	30,442	47,525	0.96	77,967
8/06	376	430	806	30,818	47,955	0.97	78,773
8/07	262	486	748	31,080	48,441	0.98	79,521
8/08	220	509	729	31,300	48,950	0.98	80,250
8/09	147	453	600	31,447	49,403	0.99	80,850
8/10	148	529	677	31,595	49,933	1.00	81,528
Total	31,595	49,933	81,528	31,595	49,933		81,528
SE [c]	353						353

[a] Boxed area identifies 2^{nd} and 3^{rd} quartile of run.

[b] Bold box identifies median day of passage.

[c] There is no sampling error associated with left bank since data was collected 24 hrs per day over the sampling range.

Table 3.–Summary of Chinook salmon sex composition at Eagle sonar project site, 2005.

Date	Catch	Sex M	Sex F	% Male	% Female
7/12	12	8	4	67	33
7/13	2	2	0	100	0
7/14	12	8	4	67	33
7/15	8	2	6	25	75
7/16	4	2	2	50	50
7/17	7	6	1	86	14
7/18	6	6	0	100	0
7/19	7	3	4	43	57
7/20	13	10	3	77	23
7/21	8	5	3	63	38
7/22	14	13	1	93	7
7/23	13	8	5	62	38
7/24	7	6	1	86	14
7/25	9	7	2	78	22
7/26	5	2	3	40	60
7/27	11	8	3	73	27
7/28	7	4	3	57	43
7/29	0	0	0	0	0
7/30	2	1	1	50	50
7/31	7	3	4	43	57
8/01	2	1	1	50	50
8/02	9	9	0	100	0
8/03	1	0	1	0	100
8/04	5	1	4	20	80
8/05	1	1	0	100	0
8/06	1	0	1	0	100
8/07	2	2	0	100	0
8/08	2	1	1	50	50
8/09	2	2	0	100	0
8/10	0	0	0	0	0
Total	179	121	58	68	32

Table 4.–Summary of Chinook salmon caught by mesh size and average lengths at Eagle sonar project site, 2005.

Mesh Size (inches)	Catch	% Catch	Effort (Fathom Hours)	Average Length (mm)	SD (mm)
2.75	7	4	148	750	57
4.00	27	15	131	763	97
5.50	32	18	150	737	112
6.50	48	27	122	795	87
7.50	44	25	153	801	91
8.50	21	12	130	795	78
Total	179		835		

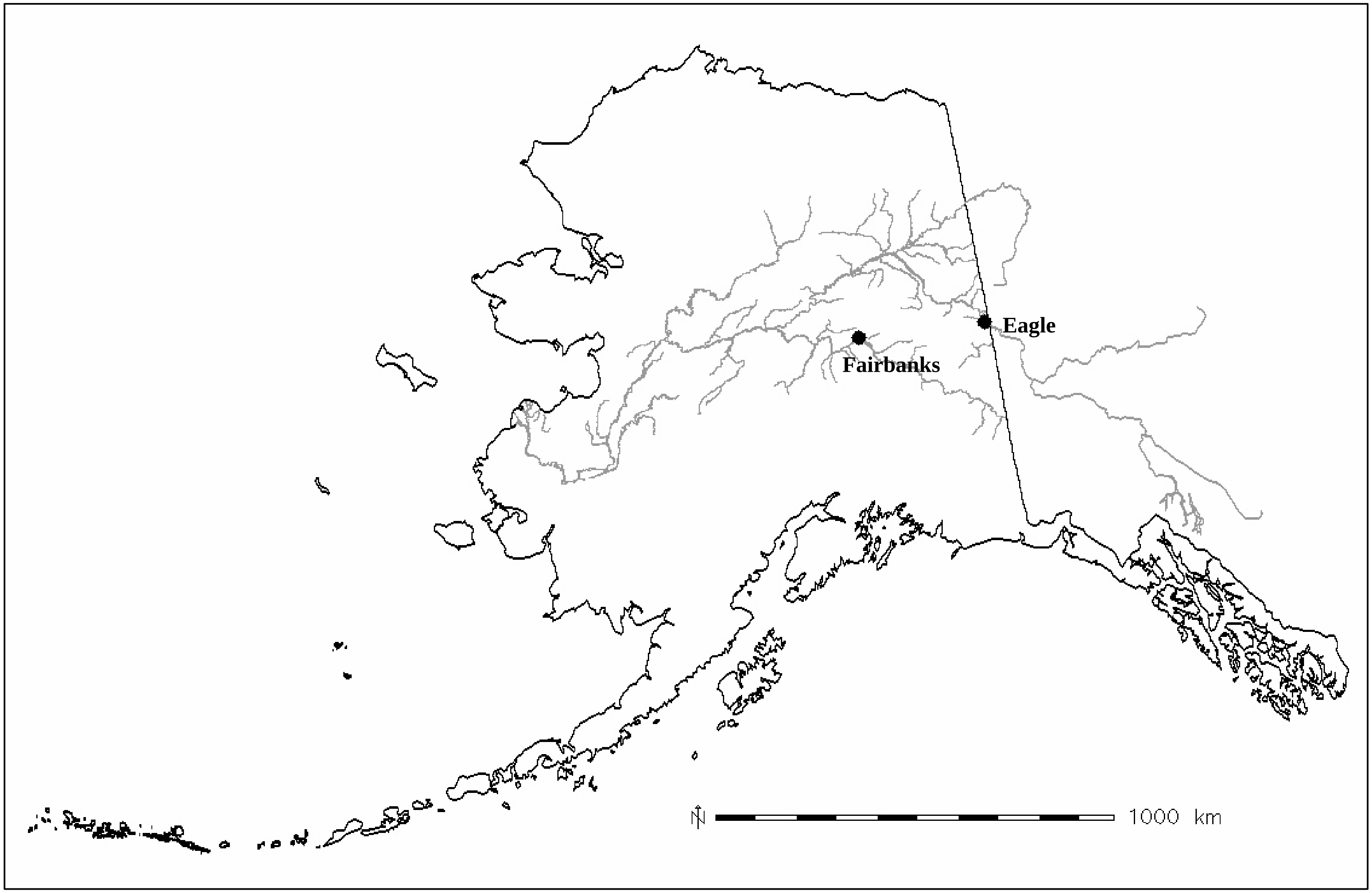


Figure 1.–Yukon River drainage.

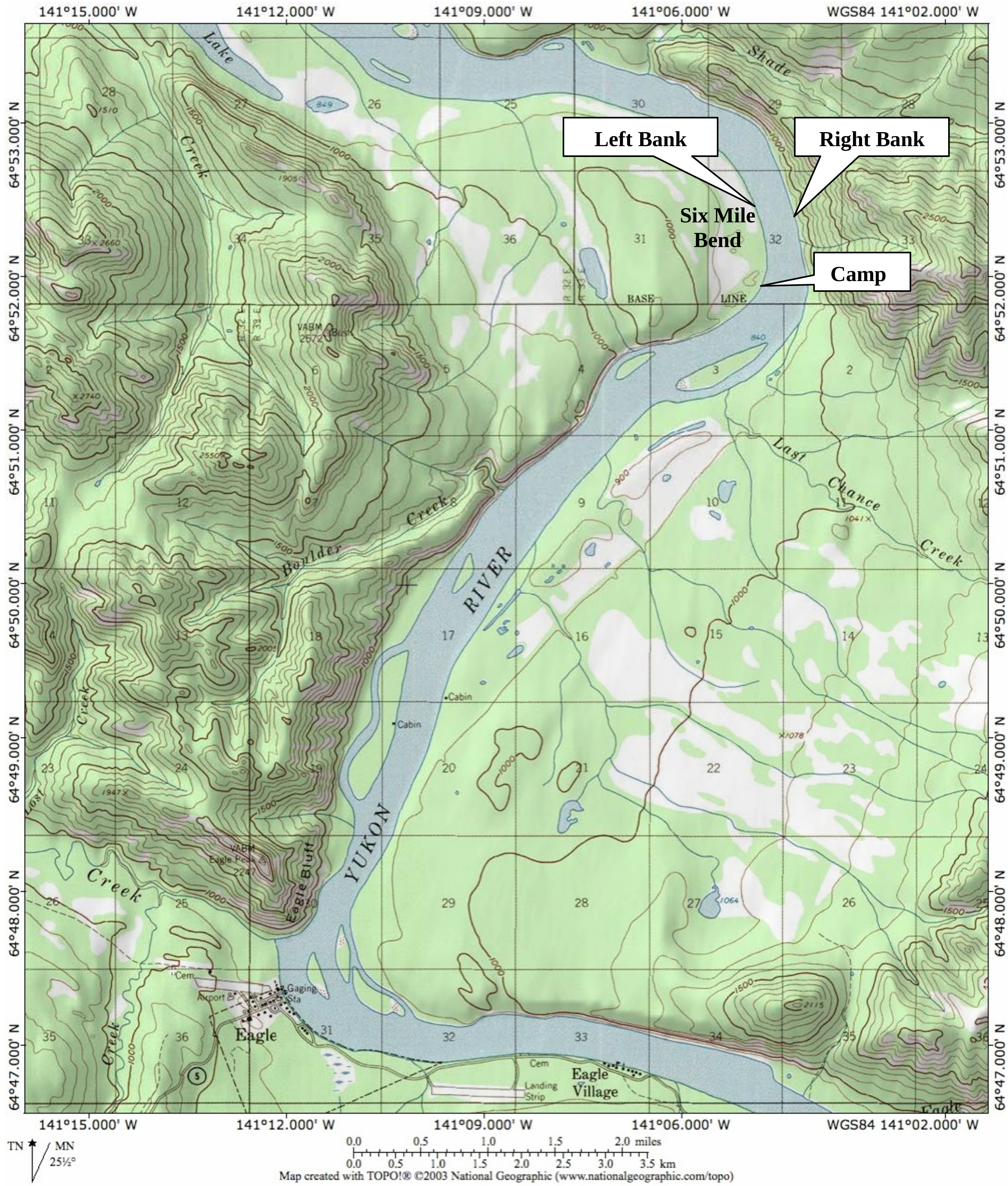


Figure 2.–Eagle sonar project site at Six-Mile Bend.

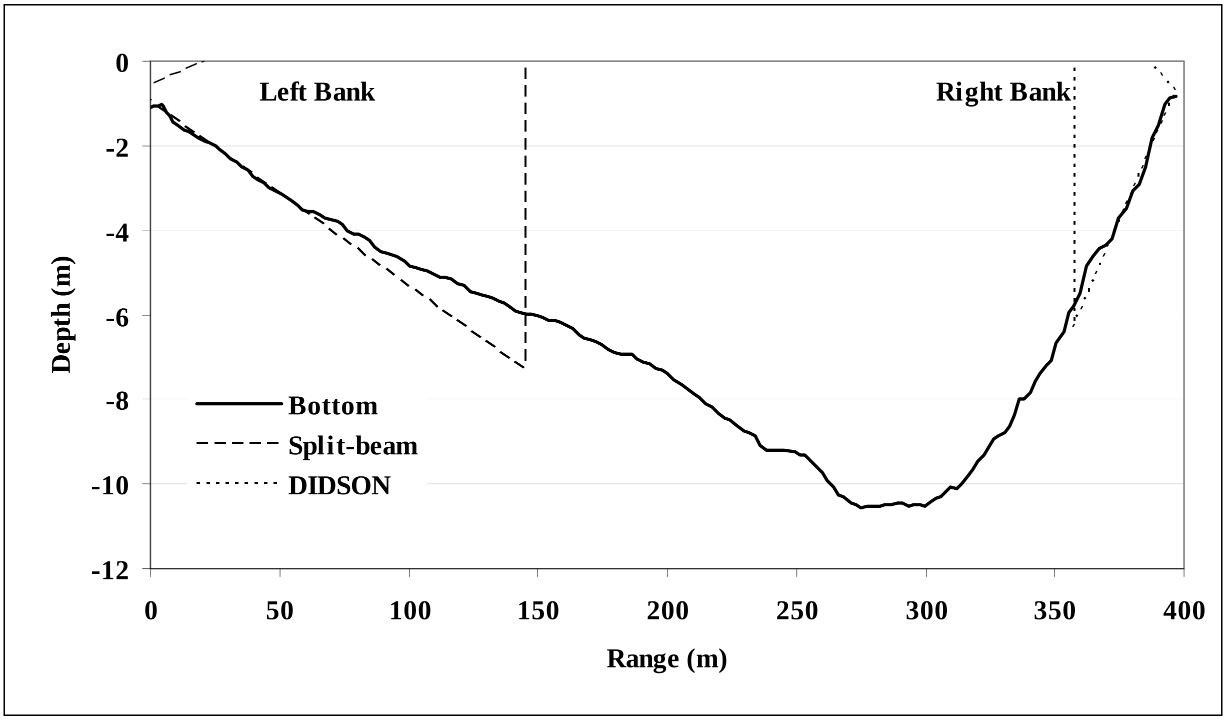


Figure 3.–Depth profile (downstream view), and ensonified zones of Yukon River at Eagle sonar project site project site, 2005.

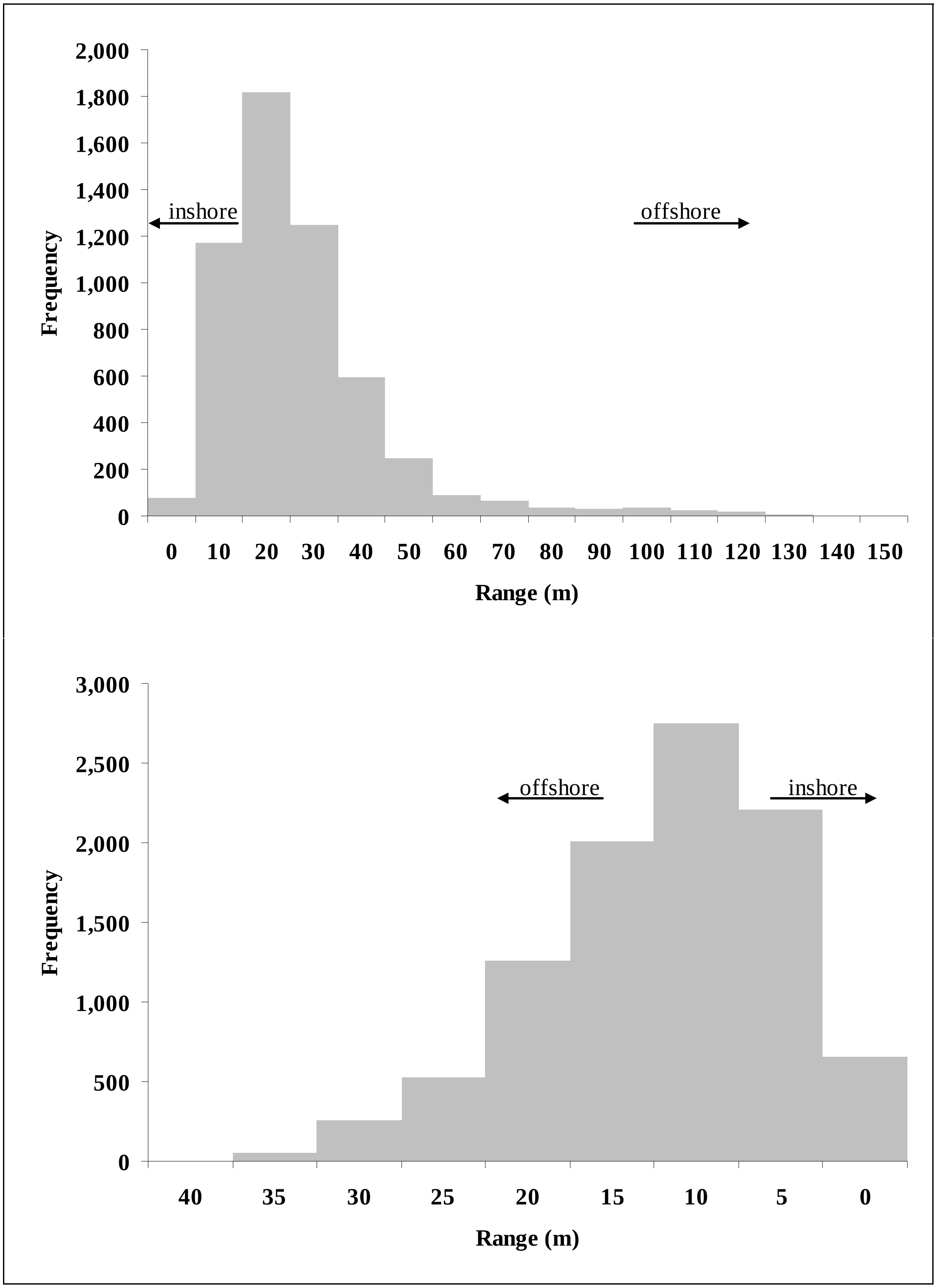


Figure 4.–Left bank (above) and right bank (below) upstream Chinook salmon horizontal distribution in the Yukon River at Eagle sonar project site, 2005.

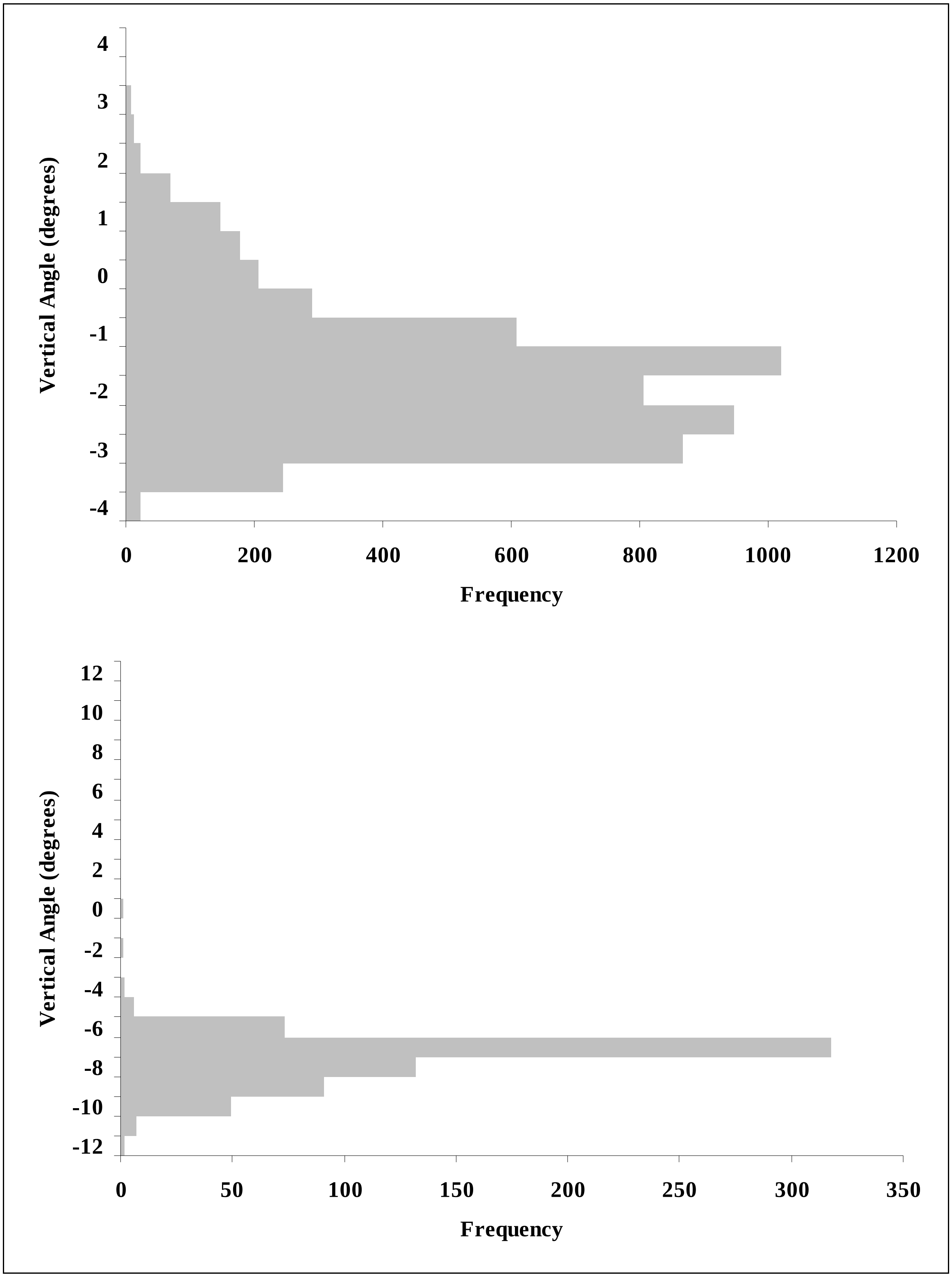


Figure 5.–Left bank (above) and right bank (below) upstream Chinook salmon vertical distribution in the Yukon River at Eagle sonar project site, 2005.

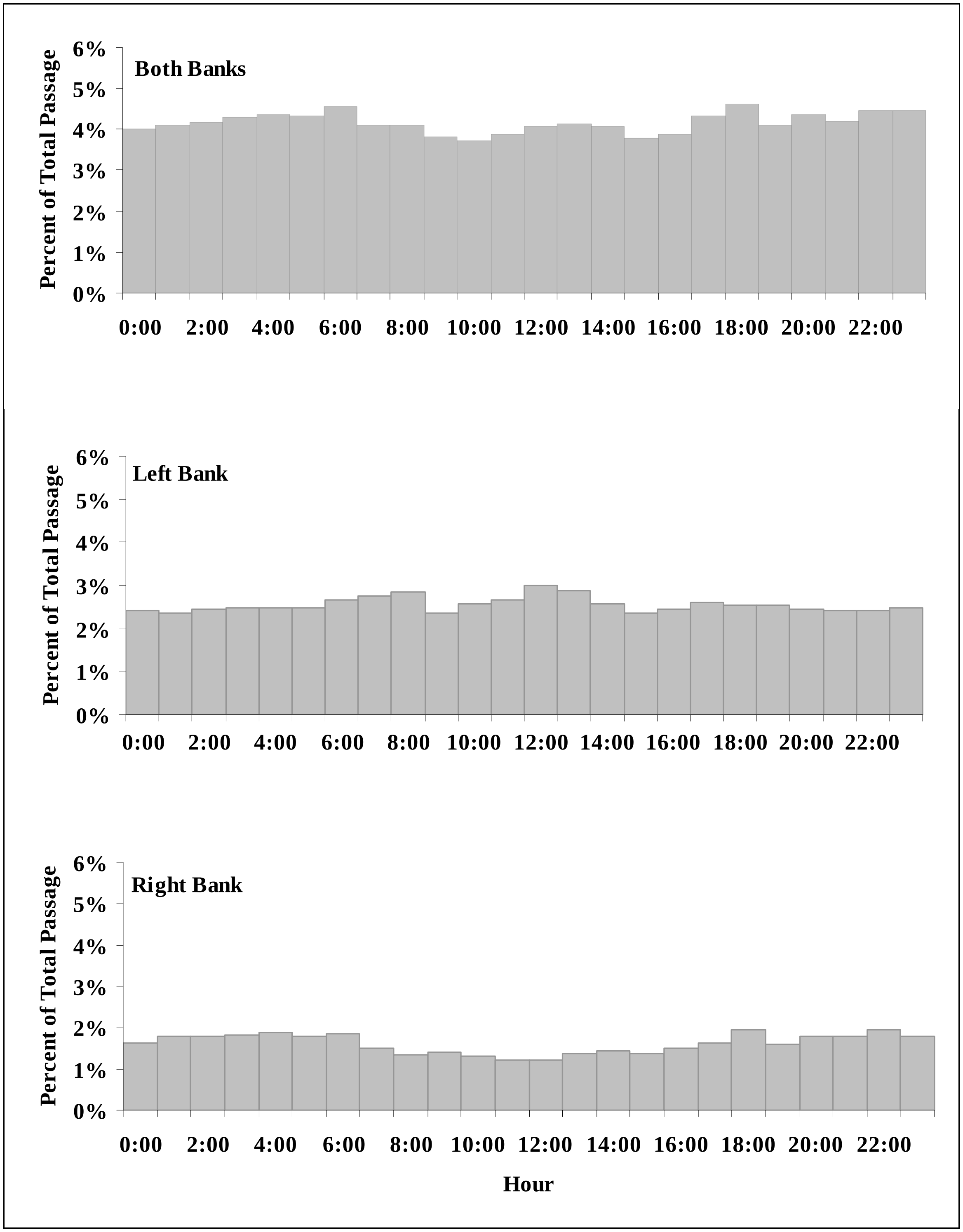
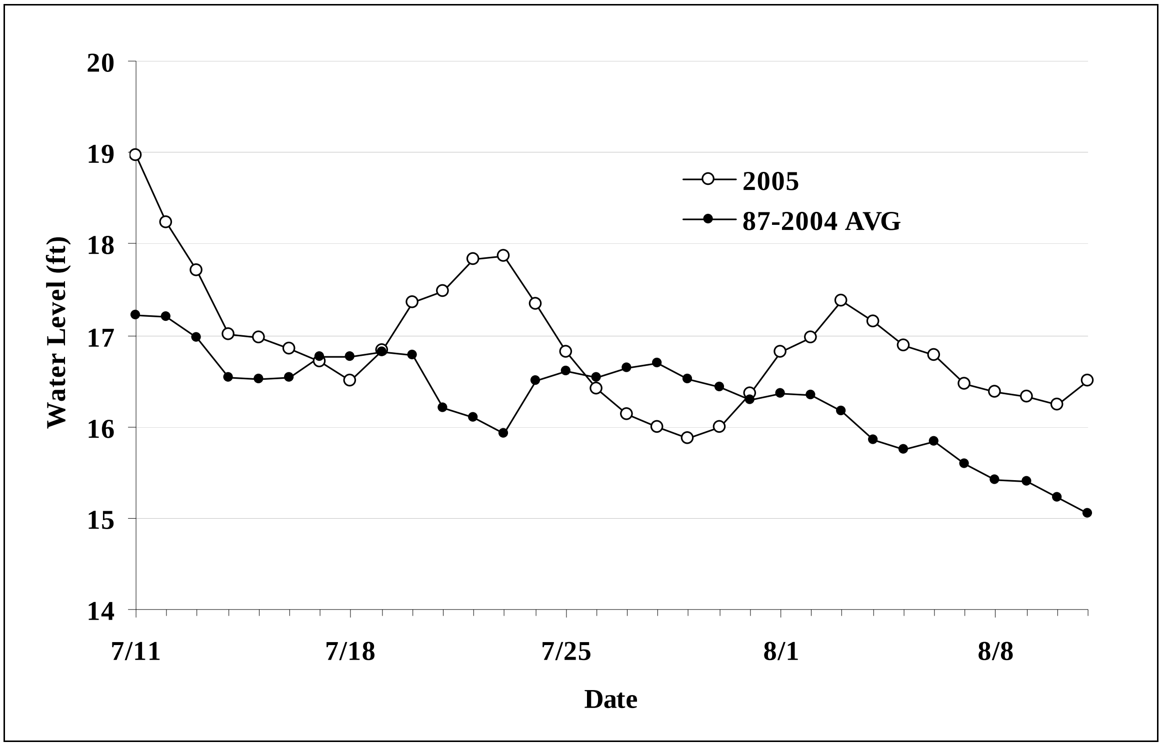


Figure 6.–Diel migration pattern of Chinook salmon observed on both banks combined (top), the left bank (middle), and right bank (bottom) of the Yukon River, at the Eagle sonar project site, July 12–August 10, 2005.



Source: United States Geological Survey.

Figure 7.–Daily water elevation measured at Eagle, 2005.

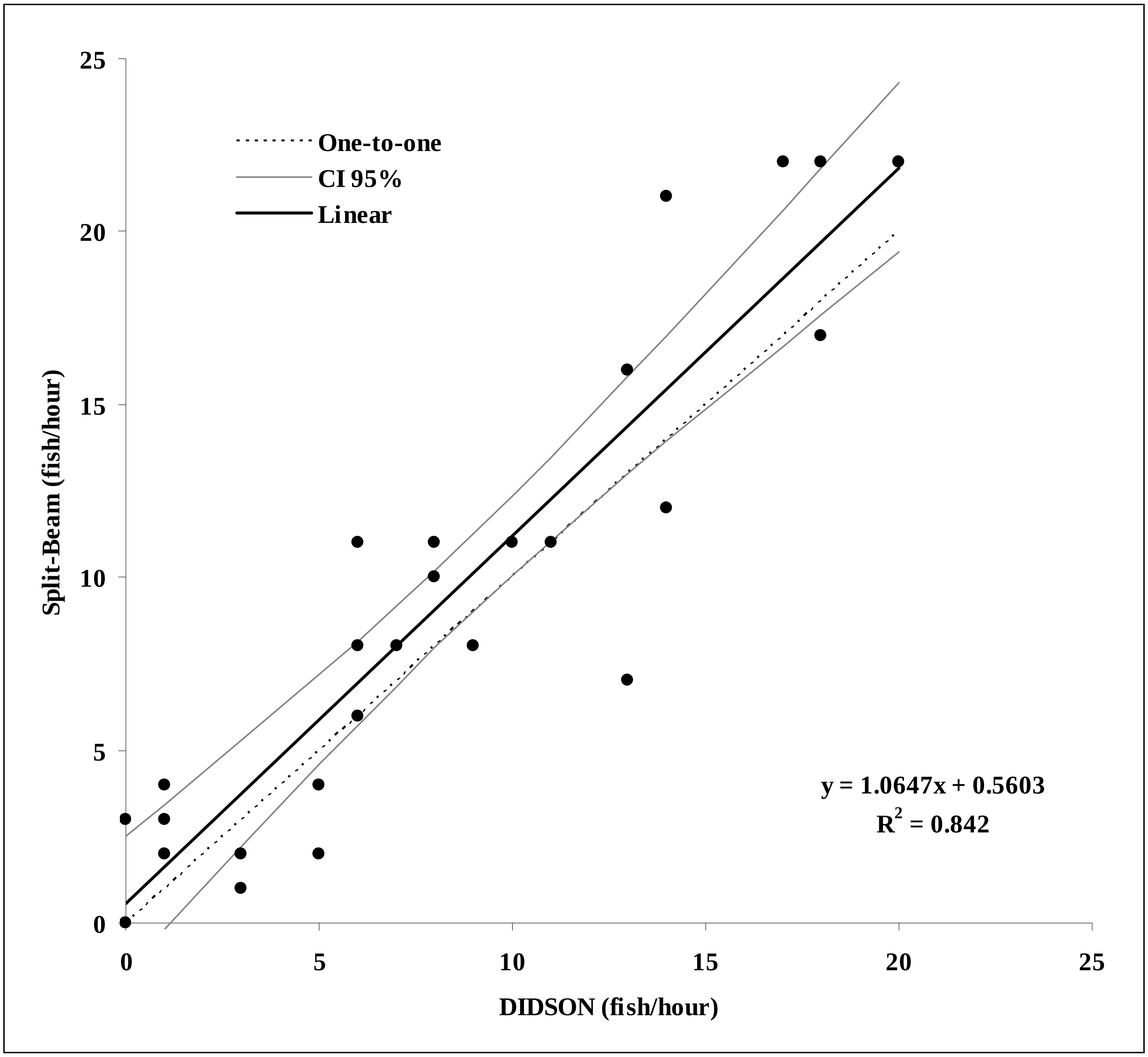


Figure 8.–Comparison of right bank nearshore fish passage between split-beam sonar and DIDSON sonar in the Yukon River, Eagle sonar project site, 2005.

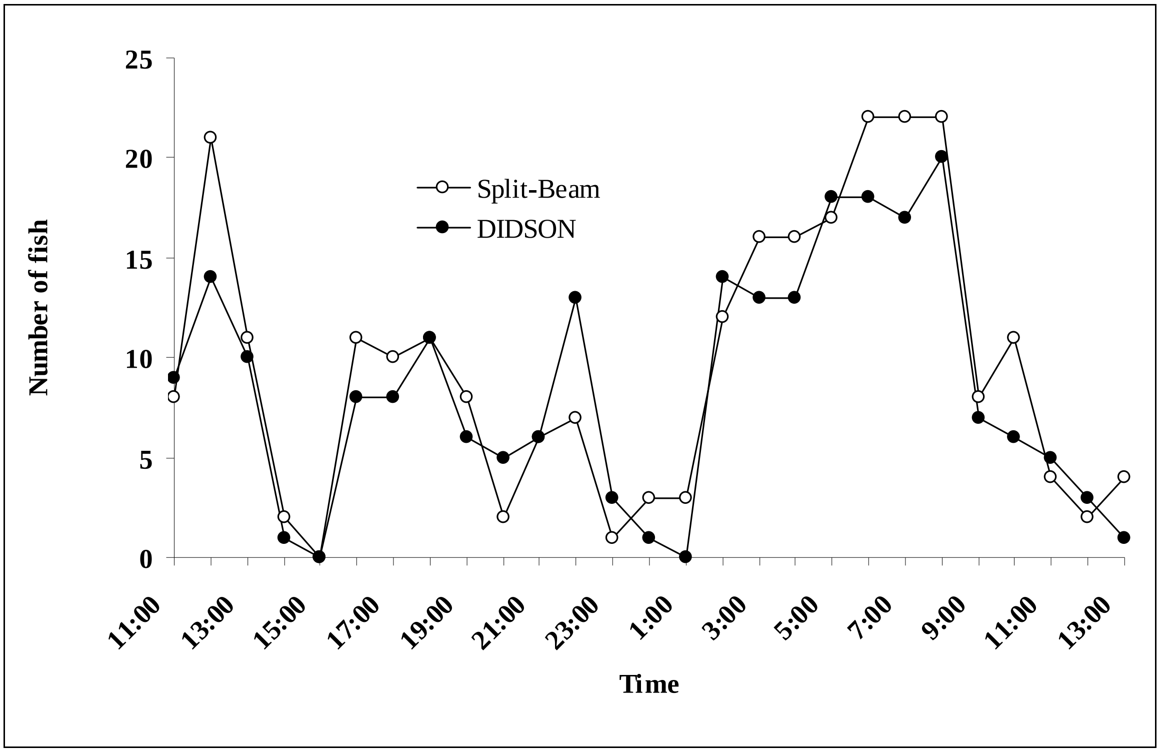


Figure 9.–DIDSON and split-beam sonar-estimated right bank fish passage Yukon River, Eagle sonar project site, July 24–25, 2005.

APPENDIX A. CLIMATE AND HYDROLOGICAL OBSERVATIONS

Appendix A1.–Climate and hydrological observations taken daily between 1800 and 2000 hours at the Eagle sonar project site, 2005.

	Precipitation	Wind		Sky	Temperature (C°)		Water Color
Date	(code) [a]	Direction	Speed (mph)	(code) [b]	Air	Water	(code) [c]
7/09	B	SE	3	B	18	17	Tr
7/10	B	calm	calm	B	18	17	Tr
7/11	A	SE	2	S	no data	no data	Tr
7/12	no data	no data	no data	no data	no data	no data	no data
7/13	B	NW	5	S	21	17	Tr
7/14	A	NW	5	S	21	18	Tr
7/15	A	NW	8	S	25	18	Tr
7/16	B	calm	calm	F	16	18	Tr
7/17	B	calm	calm	B	18	18	Tr
7/18	B	calm	calm	B	17	18	Tr
7/19	A	NW	10	S	19	16	Tr
7/20	A	SE	25	S	10	13	Tr
7/21	A	calm	calm	S	18	15	Tr
7/22	A	SE	15	S	17	14	Tr
7/23	A	calm	calm	S	17	14	Tr
7/24	A	SE	5	S	16	12	Tr
7/25	A	calm	calm	F	22	15	Tr
7/26	A	SE	10	F	21	16	Tr
7/27	A	calm	calm	B	19	16	Tr
7/28	A	calm	calm	S	19	14	Tr
7/29	A	calm	calm	F	15	15	Tr
7/30	A	calm	calm	B	13	14	Tr
7/31	A	calm	calm	B	16	14	Tr
8/01	A	calm	calm	C	11	12	Tr
8/02	B	calm	calm	S	11	13	Tr
8/03	B	S	5	B	17	13	Tr
8/04	A	calm	calm	B	17	14	Tr
8/05	B	calm	calm	S	15	14	Tr
8/06	A	calm	calm	O	17	14	Tr
8/07	A	calm	calm	O	19	14	Tr
8/08	A	calm	calm	C	14	14	Tr
8/09	A	calm	calm	F	14	15	Tr
8/10	A	calm	calm	F	21	15	Tr
Average					17	15	

[a] Precipitation code for the preceding 24-hr period: A = none; B = intermittent rain; C = continuous rain; D = snow and rain mixed; E = light snowfall; F = continuous snowfall; G = thunderstorm w/ or w/o precipitation.

[b] Instantaneous cloud cover code: C = clear, cloud cover < 10% of sky; S = cloud cover < 60% of sky; B = cloud cover 60-90% of sky; O = overcast (100%); F = fog, thick haze or smoke.

[c] Instantaneous water color code: Cl = clear; Lt = slightly murky or glacial; Br = moderately murky or glacial; Tr = heavily murky or glacial; E = brown, tannic acid stain.